2012 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
NOAA Fisheries

Executive Summary

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels with no bycatch.
3. Stock biomass: Stock adult biomass in recent years decreased from 2007 to 2009 and increased in in 2010, 2011, and 2012.
4. Recruitment: Recruitment indices are not well understood for Pribilof red king crab. Pre-recruits may not be well assessed with the survey but increased between 2005 and 2007 and decreased each year since 2009.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	1,914 (4.22)	2,175[A] (4.46)	0	0	2.7 (0.006)	227 (0.50)	
2010/11	2,255 (4.97)	2,754[B] (5.44)	0	0	4.2 (0.009)	349 (0.77)	
2011/12	2,571 (5.67)	2,775[C*] (5.68)	0	0	5.4 (0.011)	393 (0.87)	307 (0.68)
2012/13		3,325[D**] (7.33)				574 (1.27)	459 (1.01)

All units are in t (million lbs) of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2011/2012 and is hence not overfished. Overfishing did not occur during the 2011/2012 fishing year.

Notes:

A – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
B – Based on survey data available to the Crab Plan Team in September 20010 and updated with 2010/2011 catches
C – Based on survey data available to the Crab Plan Team in September 2011 and updated with 2011/2012 catches
D – Based on survey data available to the Crab Plan Team in September 2012
* – 2011/12 estimates based on 3 year running average
** – 2012/13 estimates based on weighted 3 year running average

6. Basis for 2012/2013 OFL projection:

Year	Tier	B_{MSY} t (10^6 lbs)	Current MMB_{mating} t (10^6 lbs)	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}	P*
2012/13	4b	5,136 (11.32)	3,325 (7.33)	0.65	1.0	1991/1992-2011/2012	0.18	0.49

7. The OFL distribution which quantifies uncertainty was constructed using bootstrapping methods approximating the lognormal distribution. Within assessment uncertainty was included based on the 2012 survey mature male biomass CV of 0.57.

8. The ABC recommendation incorporated a σ_b of 0.4 to account for additional uncertainty, thus reducing the ABC from an ABC_{max} of 505 t (1.11 million lbs) to 459 t (1.01 million lbs).

9. Rebuilding analyses results summary: not applicable.

Summary of Major Changes:

1. Management: There were no major changes to the 2011/2012 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series were updated with 2011/2012 data.
3. Assessment methodology: MMB was estimated with an average centered on the current year and weighted by the inverse CV.
4. Assessment results: The projected MMB increased and the OFL increased in this assessment. Total catch mortality in 2011/2012 was 5.4 t.

Responses to SSC and CPT Comments

SSC comments October 2011:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The fishery for red king crab in the Pribilof Islands district has been closed since 1999 due to concerns of low abundance, imprecision of biomass estimates, and pot bycatch of sympatric blue king crab, which are classified as overfished. Fishing mortality since the closure of the directed fishery has been limited to incidental catches in other crab fisheries and in groundfish fisheries. The SSC supports the CPT recommendation to continue using the same base years as used previously (1991 to the current year) for determination of BMSY for the Pribilof Islands red king crab stock. The SSC also supports a Tier 4b designation for this stock, noting that the estimate of mature male biomass (2.577 t) is below BMSY (5,143 t) and only slightly above MSST (2,572 t).

The SSC agrees with the CPT recommendation to include additional uncertainty (σb = 0.4) when calculating the ABC using the P approach, which results in a multiplier of 0.78 times the estimated OFL (393 t). The resulting ABC is 307 t. The SSC's support for this approach is based in large part on the recognition that the brief history of exploitation of this stock makes it difficult to identify an appropriate period of time suitable for establishing BMSY, such that the true distribution of the OFL is poorly known. The SSC recognizes that the appropriate value for σb is uncertain, and we accept the plan teams' choice given their expertise and their prior discussions on this issue.*

Estimates of mature male biomass (MMB) were calculated in the assessment as a three-year moving average using the target year's value averaged with the prior 2 years. The SSC agrees with the assessment author and the plan team that a more appropriate calculation would center the average on the target year and encourage consideration of other methods, including weighted averages, in subsequent assessments. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.

Responses to SSC Comments: Methodology for an average biomass centered on the current year and additional weighting methods were considered. CSA model development is on hold.

SSC comments June 2012:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment
none

CPT comments September 2011:

General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment
The team recommended maintaining the status quo time period of 1991-2011 in the calculation of $B_{MSYProxy}$. It was suggested that the 3-yr average be used in estimating MMB at mating in any year t, but that the actual observed MMBs in each year over the reference period should be used to calculate the BMSY Proxy. The team recommended that the 3-yr average should be calculated based on the current year, the previous year and the following year, not the current year plus the preceding two years. These calculations will be corrected for the next assessment. The team also discussed alternative methods for deriving a 3-yr average index of MMB – e.g., an average weighted by the inverse of the coefficients of variation of each annual MMB, a lowess smoothed index, and a weighted index in which the weights reflected the relative importance of the years in the average.

Responses to CPT Comments: A 3 year average centered on the current year and weighted by the inverse CV was used to calculate the MMB while unaveraged survey data was used to calculate B_{MSY}^{proxy}.

CPT comments May 2012:

General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment
none

Introduction

1. **Red king crabs, *Paralithodes camtschaticus*** (Tilesius, 1815)

2. **Distribution** - Red king crabs are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39' N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36' N lat. between 168° 00' N and 171° 00' W long and north of 55° 30'N lat. between 171° 00' W. long and the U.S.-Russian boundary (Figure 2).

3. **Stock structure** – The information on stock structure of red king crabs in the North Pacific comes from two projects. One is based on 1,800 microsatellite DNA samples from red king crabs originating from the Sea of Okhotsk to Southeast Alaska (Seeb and Smith 2005). In the Bering Sea Aleutian Island region, samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound. A more recent study describes the genetic

distinction of Southeast Alaska red king crab compared to Kodiak and the Bering Sea; the latter two being similar (Grant and Cheng 2012).

4. **Life History** - Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. After copulation, eggs are fertilized as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

   Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006) and estimates vary. Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

   The reproductive cycle of Pribilof Islands red king crabs has not been established, however, in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous Bristol Bay red king crab females (brooding their first egg clutch) extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990) resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for eastern Bering Sea red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

5. **Management history** - Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crabs *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof red and blue king crab fisheries which was implemented in 1998. From 1999 to 2011/2012 the Pribilof fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for complete management history).

   Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

   Pribilof red king crabs occur as bycatch in the eastern Bering Sea snow crab (*Chionocetes opilio*), eastern Bering Sea Tanner crab (*Chionocetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof blue king crab fisheries. Many of these fisheries have been closed or recently re-opened so the opportunity to catch Pribilof red king crab is limited. Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries.

Data

1. The standard survey time series data updated through 2012 and the standard groundfish discards time series data updated through 2012 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2011/2012 data.

2. a. Total catch:
   Crab pot fisheries
   Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 1 and 2), the seasons when red king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons red king crab and blue king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2011/2012 fishing season.

   b. Bycatch and discards:
   Crab pot fisheries
   Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2012 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

   $$\text{Weight (g)} = A * \text{CL(mm)}^B \quad (1)$$

   $$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

   Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. To assess crab mortalities in these pot fisheries a 50% handling mortality rate is applied to these estimates.

   Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here.

   In 2011/2012, there were no Pribilof Islands red king crab incidentally caught in the crab fisheries (Table 3).

   Groundfish pot, trawl, and hook and line fisheries
   The 2011/2012 NOAA Fisheries Regional Office (J. Mondragon, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all crab combined by federal reporting areas. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2010 to June 2011. For Pribilof Islands red king crab, Areas 513 and 521 are included. It is noted that due to the extent of Area 513 into the Bristol Bay District, groundfish non-retained crab catches for Pribilof Islands red king crab may be overestimated. In 2012/2013 these data will be available in smaller units so that the management

unit for each stock can be more appropriately represented. To estimate sex ratios for 2011/2012 catches, sex ratios by size and sex from the 2012 EBS bottom trawl survey were applied. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been discriminated by each year's survey proportions (Table 3).

In 2011/2012, 7.21 t of male and female blue king crab were caught in fixed gear (1.24 t) and trawl gear (5.97 t) groundfish fisheries which is 33% greater than was caught in 2010/2011 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (83%) followed by longline (12%), and pot (5%) fisheries. The targeted species in these fisheries were Pacific cod (17%), flathead sole (38%), pollock (4%), yellowfin sole (40%), and traces <1% found in the rock sole fisheries. Unlike previous years no bycatch was observed in Alaska plaice fisheries in 2011/2012.

c. Catch-at-length: NA

d. Survey biomass:
The 2012 NOAA Fisheries EBS bottom trawl survey results (Foy and Armistead in press) are included in this SAFE report (Figure 6). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 5). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)}$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)} \quad (3)$$

Historical survey data are available from 1975 to the present (Table 4, Figure 6). It should be noted that the survey data analyses were standardized in 1980.

In 2012, red king crab were caught at 12 of the 77 stations in the Pribilof District; 10 stations in the high-density sampling area and 2 stations in the standard-density sampling area (Foy and Armistead in press, Figure 7). The density of legal-sized males caught at a station ranged from 67 to 2,443 crab nmi^{-2}. Legal-sized male red king crab were caught at 9 of the 77 stations in the Pribilof District with a biomass estimate (± 95% CI) of 4,360 ± 4,846 t and an abundance estimate (± 95% CI) of 1.2 ± 1.3 million crab. Legal-size males represented 91% of the total male biomass but were below the average of 5,284 ± 5,905 t from the previous 20 years (Figure 8). The majority of the legal-sized males were distributed around and to the northeast of St. Paul Island.

Mature males were encountered at 9 of the 77 stations in the Pribilof District; 9 stations in the high-density sampling area, and zero stations in the standard-density sampling area. Two stations accounted for 81% of all mature red king crab caught. The biomass estimate of mature males was 4,477 ± 5,031 t and represented 93% of the total male biomass with the remaining 7% represented by 336 ± 636 t of immature male red king crab. Mature males were distributed around St. Paul Island in the nearshore shallow water stations and to the northeast of St. Paul Island (Figs. 20 and 21).

The 2012 size-frequency for red king crab males shows a similar number of oldshell and very oldshell legal-sized males compared to 2011. In 2012, 51% of the legal-sized males were new hardshell crabs and distributed northeast of St. Paul Island. Forty-one percent of the legal-sized males were in oldshell and very oldshell condition and primarily distributed southeast of St. Paul Island.

The 2012 biomass estimate of mature-sized red king crab females was 663 ± 710 t and abundance was 0.4 ± 0.5 million crab, representing 100% of the total female biomass collected during the survey. A majority of the mature females were carrying uneyed embryos with 43% of the mature females in new hardshell condition. The majority of mature females with uneyed embryos were in the 130 mm to 140 mm CL size class.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past although is currently not in development.

Calculation of MMB

Taking an average biomass across 3 years centered on the current year to calculate the MMB in the most recent year was considered to reduce the effect of high uncertainty in the survey based area swept estimates (Figure 9). In addition, this average was weighted by the inverse CV of the survey biomass estimate to account for changes in variability among years. A loess weighting function was also considered but did not fit the data trends adequately. An unweighted average was also considered but overfit the data in years with a large amount of variance (Figure 10). ***Therefore in this analysis the MMB was estimated by a three year moving average MMB weighted by the inverse CV.*** Figure 11 shows the three year running average of MMB_{mating} with confidence intervals and CVs used for the analyses in this SAFE. The survey time series with three year moving weighted averages for each major size class for males and females is presented in Table 5.

Calculation of the OFL

1. Based on available data, the ***author recommended classification for this stock is Tier 4*** for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

2. In Tier 4, Maximum Sustainable Yield is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at mating (MMB_{mating}) which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of unknown sex ratios, a male only fishery, and the complicated female crab life history where molting and mating occur simultaneously. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}.B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

   The mature stock biomass ratio β where $B/B_{MSY}^{prox} = 0.25$ represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 12). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values

for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where *B* is greater than β includes the product of a scalar (**γ)** and *M* (equations 5 and 6) where the default **γ** value is 1 and *M* for Bering Sea red king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

3. Calculation of B_{MSY}^{prox}:
The time period for establishing $B_{MSYproxy}$ was assumed to be representative of the stock being fished at an average rate near F_{MSY} fluctuating around B_{MSY}. The criteria to select the time period was based on 2011 CPT recommendations for this stock. For this assessment B_{MSY}^{prox} was calculated as the average MMB_{mating} from 1991 to current based on the observation that red king crab were relatively uncommon in the area prior to 1991 and the time series is not long enough to consider additional periods. Previously, an alternative time period was considered from 2000 to current because this time period represents the only period where the MMB oscillated relatively consistently over time without fishing pressure. However, not enough data exists to suggest a shift in productivity in the time series and there are only a few years with any exploitation. The recommendation for the entire time period was based on assessment of following established criteria:
    A. Production potential
        1) The stock does not appear to be below a threshold for responding to increased production given that increases in recruitment (120 – 134 mm males) lead to increases in adult biomass (Figure 13).
        2) An estimate of surplus production ($ASP = MMB_{t+1} – MMB_t + total\ catch_t$) suggested that surplus existed prior to each increase in recruitment and mature male biomass in the mid 1990s, mid 2000s, and 2010s.
        3) A climate regime shift where temperature and current structure changes are likely to impact red king crab larval dispersal and subsequent juvenile crab distribution. Subsequent to the 1978 regime shift in the North Pacific, a small increase in production of red king crab occurred in the Pribilof Islands occurred but substantial increases did not occur until the mid 1990s. There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted to determine if subsequent climate events in the Bering Sea led to increases in production observed by the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early in later years (Figure 14).
    B. Exploitation rates fluctuated during the open fishery periods from 1993 to 1998 while total catch increased quickly in 1993 before declining rapidly until the fishery was closed in 1999 (Figure 15). The current F_{MSY}^{proxy} assume *F=M* is 0.18 so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals. However, too few years with exploitation exist for there to be a trend here.
    C. No trend is apparent when comparing the ln (recruits/MMB) with exploitation on MMB.

4. OFL specification:
a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure

12) where Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(4)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0$; $F_{OFL} \leq F_{MSY}$	(6)

b. The MMB_{Mating} projection is based on application of M from the 2012 NMFS trawl survey (July 15) to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 7). Catch mortalities are estimated from the proportion of catch mortalities in 2010/2011 to the 2011 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (7)$$

where, MMB_{Survey} is the mature male biomass at the time of the survey, $e^{-PM(sm)}$ is the survival rate from the survey to mating. PM(sm) is the partial M from the time of the survey to mating (8 months).

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 7).

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 8).

$$\text{Projected Total Catch OFL} = [1 - e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (8)$$

where $[1 - e^{-Fofl}]$ is the annual fishing mortality rate.

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as:

$$\mu_{LMB} = [\text{Total LMB retained and non-retained catch}] / LMB_{Fishery} \quad (9)$$

$$\mu_{MMB} = [\text{Total MMB retained and non-retained catch}] / MMB_{Fishery} \quad (10)$$

5. Recommendations:
For ***2011/2012 B_{MSY}^{prox}=5,136 t of MMB_{mating} derived as the mean of 1991/1992 to 2011/2012***. The stock demonstrated highly variable levels of MMB_{mating} during these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2012/2013 was estimated at 3,325 t for B_{MSY}^{prox}. **The *B/B_{MSY}^{prox} =0.65 and F_{OFL}=0.11.*** The biomass reference option B/B_{MSY}^{prox} is < 1, therefore the ***stock status level is b*** (equation 5). For the 2012/2013 fishery, the ***total catch OFL was estimated at 574 t*** of crab and legal male catch OFL was estimated at 389 t of crab. The ***projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ are 0.11 and 0.12 respectively.***

Red king crabs in the Pribilof Islands have been historically harvested with blue king crabs and are currently the dominant of the two species in this area. There are concerns as to the low reliability of survey biomass estimates and the high levels of blue king crab incidental catch mortality that would occur in a directed Pribilof Islands red king crab fishery.

Calculation of the ABC

1. To calculate an Annual Catch Limit (ACL) to account for scientific uncertainty in the OFL, an acceptable biological catch (ABC) control rule was developed such that ACL=ABC. The ABC is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty to account for uncertainty outside of the assessment methods (σ_b) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

   Specification of the probability distribution of the OFL used in the ABC:
   A distribution for the OFL which quantifies uncertainty was constructed using bootstrapping methods approximating the lognormal distribution. This involves generating values for *M* and annual MMB_{mating} (e.g. by assuming that MMB is log-normally distributed and *M* is normally distributed) and for each simulation calculating the OFL using the standard methods in sections 3 and 4 of the OFL Calculation section above. The OFL distribution for Pribilof Island red king crab is skewed to the right due to the patchy spatial distribution and small abundance which affects the variability of density estimates among trawl survey stations. This lognormal distribution suggests that use of the mean value (as opposed to the median) of the distribution would be appropriate as it changes with greater variability.

2. List of variables related to scientific uncertainty considered in the OFL probability distribution:
   Compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands red king crab is high due to insufficient data and the small distribution of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass for the most recent year is 0.594 and has ranged between 0.357 and 0.786 since the 1995 peak in biomass.

3. List of additional uncertainties considered for alternative σ_b applications to the ABC.
   Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:
   - Survey catchability and natural mortality uncertainties are not estimated but are rather pre-specified.
   - F_{msy} is assumed to be equal to γM when applying the OFL control rule while γ is assumed to be equal to 1 and *M* is assumed to be known.
   - The coefficients of variation for the survey estimates of abundance for this stock are very high.

- B_{msy} is assumed to be equivalent to average mature male biomass. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1981-1988 and 1993-1999. Therefore, considerable uncertainty exists with this estimate of B_{msy}.

Given the relative amount of information available for Pribilof Island's red king crab, ***the author recommended ABC includes an additional σ_b of 0.4***.

4. Recommendations:
For 2012/2013 using the recommended B_{MSY}^{prox}, the multiplier equivalent to a P* of 0.49 was 0.88. The ***ABC_{max} was thus estimated to be 505 t***. Incorporating additional uncertainty by applying a σ_b of 0.4 resulted in a multiplier of 0.80 and a ***recommended ABC of 459 t***.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	1,914	2,175[A]	0	0	2.7	227	
2010/11	2,255	2,754[B]	0	0	4.2	349	
2011/12	2,571	2,775[C*]	0	0	5.4	393	307
2012/13		3,325[D*]				574	459

All units are in t of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2011/2012 and is hence not overfished. Overfishing did not occur during the 2011/2012 fishing year.
Notes:
A – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
B – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
C – Based on survey data available to the Crab Plan Team in September 2011 and updated with 2011/2012 catches
D – Based on survey data available to the Crab Plan Team in September 2012
* – 2011/12 estimates based on 3 year running average
** – 2012/13 estimates based on weighted 3 year running average

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Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count pot^{-1})
1973/1974	0	0	0
1974/1975	0	0	0
1975/1976	0	0	0
1976/1977	0	0	0
1977/1978	0	0	0
1978/1979	0	0	0
1979/1980	0	0	0
1980/1981	0	0	0
1981/1982	0	0	0
1982/1983	0	0	0
1983/1984	0	0	0
1984/1985	0	0	0
1985/1986	0	0	0
1986/1987	0	0	0
1987/1988	0	0	0
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	380,286	1183.02	11
1994/1995	167,520	607.34	6
1995/1996	110,834	407.32	3
1996/1997	25,383	90.87	<1
1997/1998	90,641	343.29	3
1998/1999	68,129	246.91	3
1999/2000 to 2010/2011	0	0	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, 1993-2007/08 (Bowers et al. 2011).

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400[a]	34,885
1996	66	90	2,730[a]	29,411
1997	53	110	2,230[a]	28,458
1998	57	57	2,398[a]	23,381
1999-2010/11	Fishery Closed			

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2011; D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992	0.00	0.00	0.00	0.48	45.71
1992/1993	0.00	0.00	0.00	16.12	175.93
1993/1994	0.00	0.00	0.00	0.60	131.87
1994/1995	0.00	0.00	0.00	0.27	15.29
1995/1996	0.00	0.00	0.00	4.81	6.32
1996/1997	0.00	0.00	0.00	1.78	2.27
1997/1998	0.00	0.00	0.00	4.46	7.64
1998/1999	0.00	0.91	11.34	10.40	6.82
1999/2000	1.36	0.00	8.16	12.40	3.13
2000/2001	0.00	0.00	0.00	2.08	4.71
2001/2002	0.00	0.00	0.00	2.71	6.81
2002/2003	0.00	0.00	0.00	0.50	9.11
2003/2004	0.00	0.00	0.00	0.77	9.83
2004/2005	0.00	0.00	0.00	3.17	3.52
2005/2006	0.00	0.18	1.81	4.53	24.72
2006/2007	1.36	0.14	0.91	6.99	21.35
2007/2008	0.91	0.05	0.09	1.92	2.76
2008/2009	0.09	0.00	0.00	1.64	6.94
2009/2010	0.00	0.00	0.00	0.33	2.45
2010/2011	0.00	0.00	0.00	0.30	3.87
2011/2012	0.00	0.00	0.00	0.62	4.78

Table 4. Pribilof Islands District red king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Mature Male Abundance	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1975/1976	0	0	0	0	0	10
1976/1977	50778	162	144	162	162	80
1977/1978	76159	116	103	0	253	120
1978/1979	367140	1228	686	1228	1228	42
1979/1980	279707	859	205	790	859	76
1980/1981	383898	1312	959	1312	1317	195
1981/1982	80928	299	246	299	299	97
1982/1983	331947	1440	1277	1440	1458	673
1983/1984	122661	518	460	486	544	216
1984/1985	64331	261	232	233	261	67
1985/1986	16823	60	54	60	60	0
1986/1987	38419	135	120	135	135	57
1987/1988	18611	53	47	53	53	25
1988/1989	66189	104	92	43	797	732
1989/1990	754994	1498	1328	854	2154	1846
1990/1991	617113	897	795	109	6815	1775
1991/1992	2435400	4335	3823	1295	4959	3860
1992/1993	1451102	3238	2780	2479	3505	2612
1993/1994	3532420	9687	7388	9017	9962	4837
1994/1995	3114248	9052	7436	7994	9600	3397
1995/1996	7098444	24282	21139	22428	24854	6199
1996/1997	555428	2323	1971	2292	2389	1456
1997/1998	1554857	6056	5035	5843	7528	1442
1998/1999	772660	2282	1778	1749	2688	1262
1999/2000	1939076	5422	4800	4394	8682	4762
2000/2001	1538502	4239	3757	3773	4393	734
2001/2002	3662559	8434	7476	5663	10714	4333
2002/2003	1891296	6916	6129	6894	6923	571
2003/2004	1470902	5280	4678	5184	5280	1644
2004/2005	811871	3563	3157	3563	3710	983
2005/2006	247739	1219	1067	1219	1272	2207
2006/2007	1370143	6762	5983	6484	6859	1406
2007/2008	1637966	7176	6362	6947	7378	2534
2008/2009	1305315	5375	4763	5022	5698	2099
2009/2010	887543	2454	2175	2088	2498	546
2010/2011	895960	3107	2754	2881	3137	468
2011/2012	1015866	3834	3398	3751	3878	817
2012/2013	1246228	4477		4360	4813	663

Table 5. Three year running average weighted by inverse CV of Pribilof Islands District red king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature Male Abundance	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1975/1976	50778	162	144	162	162	50
1976/1977	63468	139	123	162	208	71
1977/1978	152908	550	488	746	592	80
1978/1979	220382	797	304	939	826	79
1979/1980	352954	1090	410	1068	1092	114
1980/1981	235031	844	543	816	845	126
1981/1982	263874	1005	872	1005	1012	316
1982/1983	187537	707	627	692	722	312
1983/1984	188276	685	608	676	700	282
1984/1985	57969	321	285	302	330	148
1985/1986	34275	171	152	156	171	63
1986/1987	23077	89	79	89	89	41
1987/1988	41369	102	91	84	395	342
1988/1989	269378	582	516	347	1045	960
1989/1990	469735	855	758	365	2836	1436
1990/1991	1208509	2348	2082	796	4544	2563
1991/1992	1453728	2953	2597	1540	4891	2823
1992/1993	2599092	5323	4628	3836	5726	3860
1993/1994	2823737	6847	4869	5894	7245	3699
1994/1995	4101411	16622	14150	15163	17148	5001
1995/1996	3592083	11748	10022	10773	12117	4018
1996/1997	3007134	10915	9591	10178	11376	3285
1997/1998	1049978	3154	2461	2890	3814	1393
1998/1999	1509670	4112	3401	3558	5770	2298
1999/2000	1498918	3712	3284	3117	4792	2057
2000/2001	2654396	5544	4914	4415	7090	2942
2001/2002	2605602	5948	5271	5064	6527	1461
2002/2003	2444332	6785	6013	5902	7420	1797
2003/2004	1413782	5167	4577	5127	5232	969
2004/2005	872860	3280	2906	3254	3323	1521
2005/2006	734057	4360	3853	4228	4439	1454
2006/2007	975306	5572	4927	5383	5653	2068
2007/2008	1435771	6533	5792	6266	6718	2042
2008/2009	1211693	5380	4768	5060	5574	1718
2009/2010	1016210	3669	3252	3326	3809	906
2010/2011	937126	3124	2769	2889	3164	578
2011/2012	1072846	3703	3282	3532	3816	616
2012/2013	1127460	4175		4076	4366	729

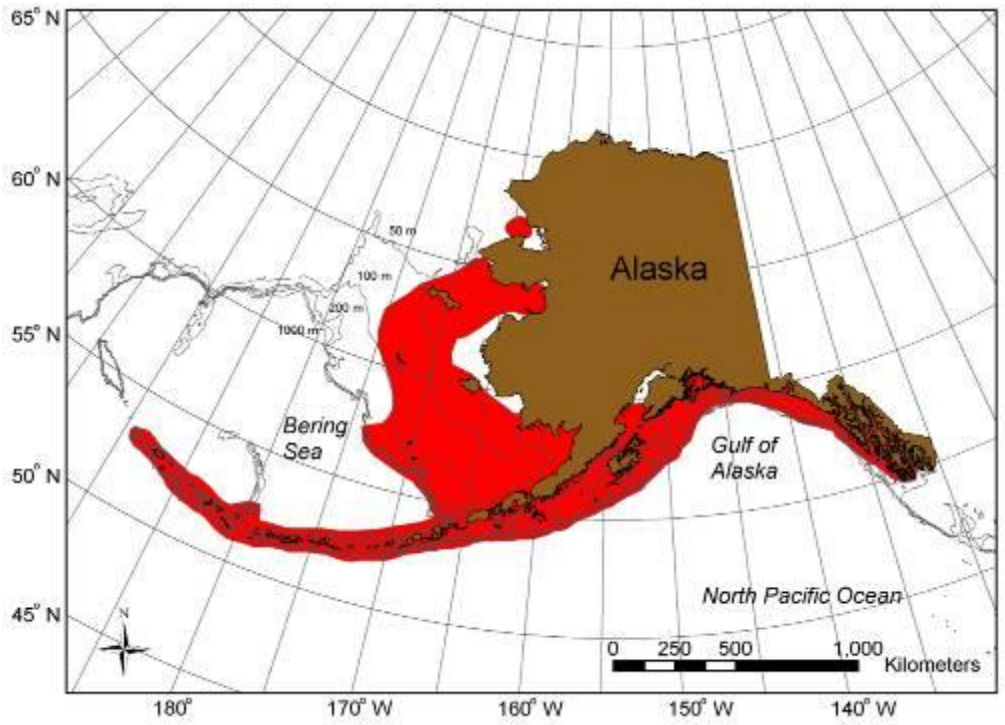

Figure 1. Red king crab distribution.

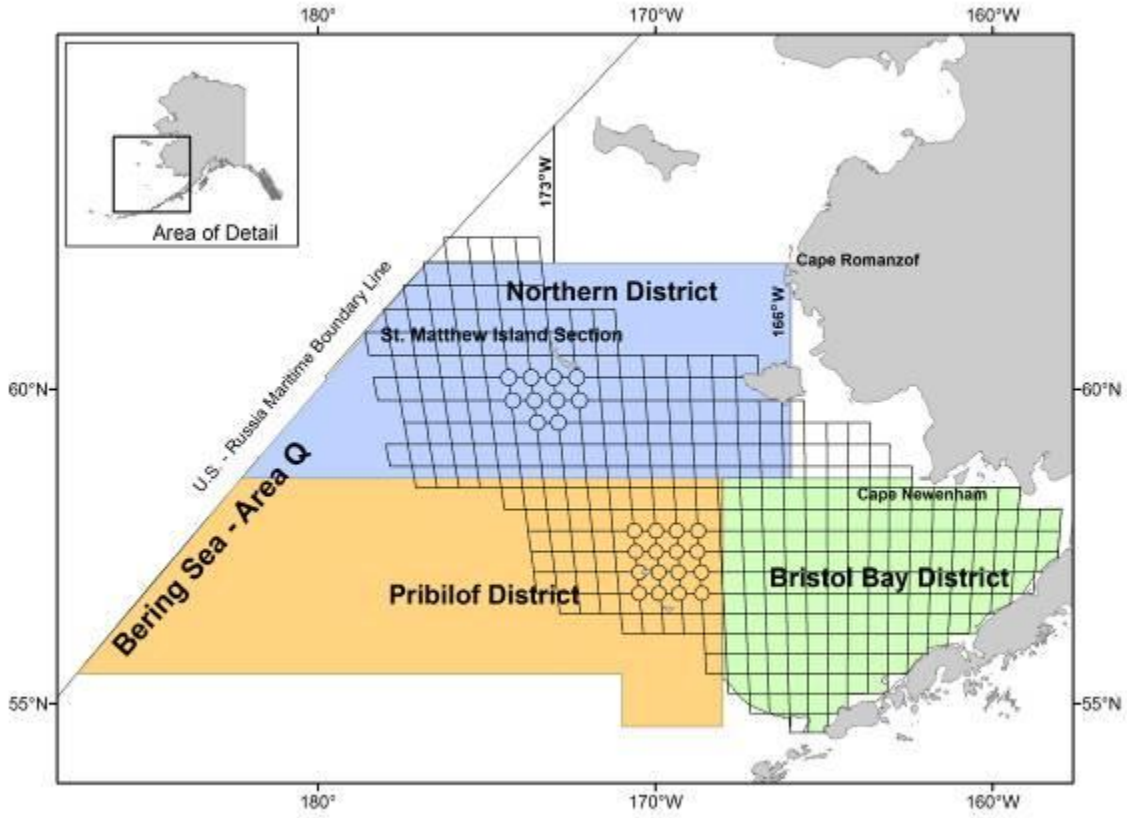

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

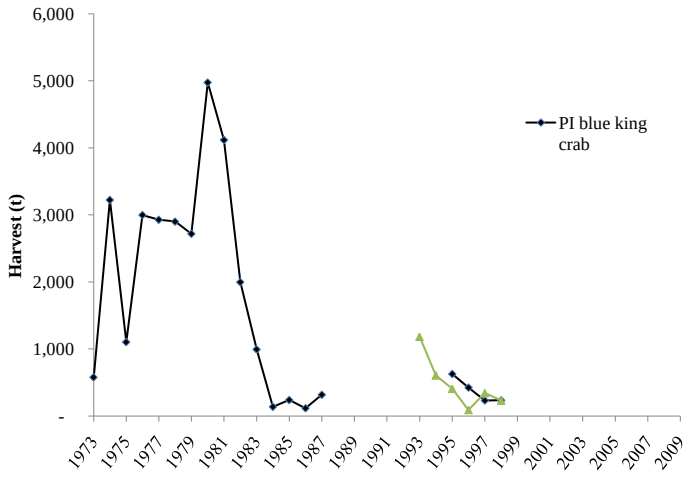

Figure 3. Historical harvests and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

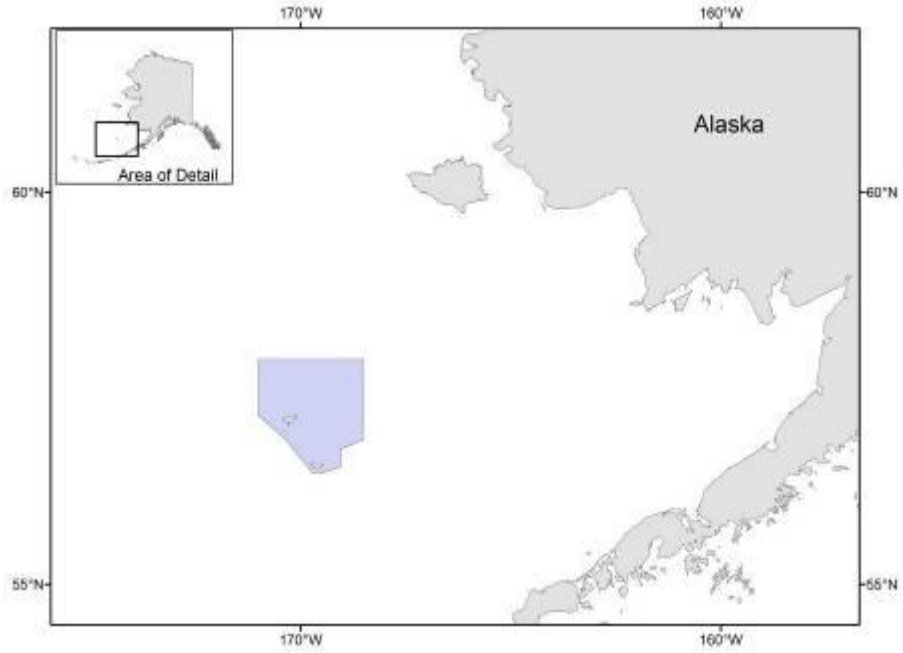

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

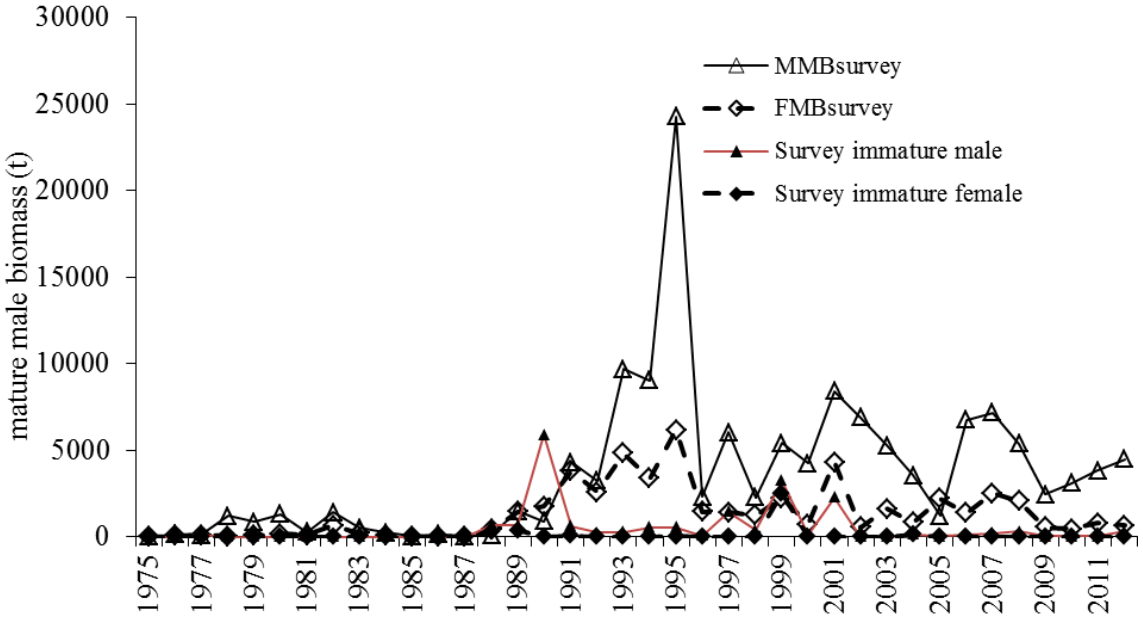

Figure 5. Time series of Pribilof Island blue king crab estimated from the NMFS annual EBS bottom trawl survey.

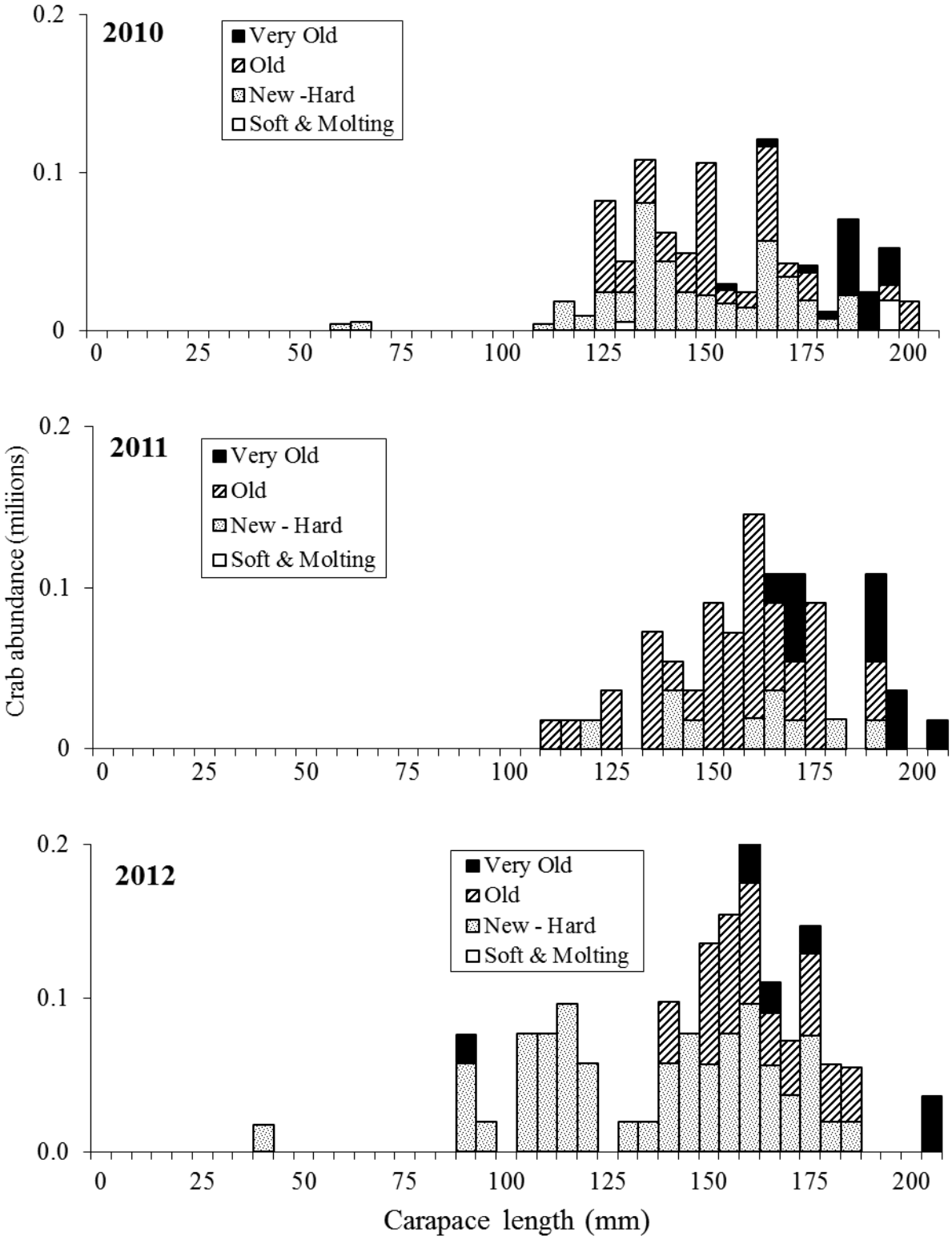

Figure 6. Distribution of Pribilof Island red king crab in 5 mm length bins by shell condition for the last 3 surveys.

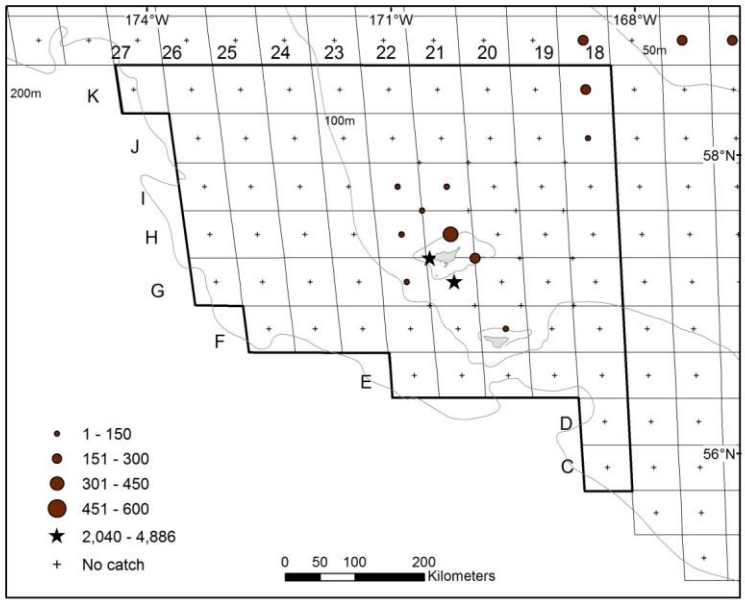

Figure 7. Total density (number nm^{-2}) of red king crab in the Pribilof District in the 2012 EBS bottom trawl survey.

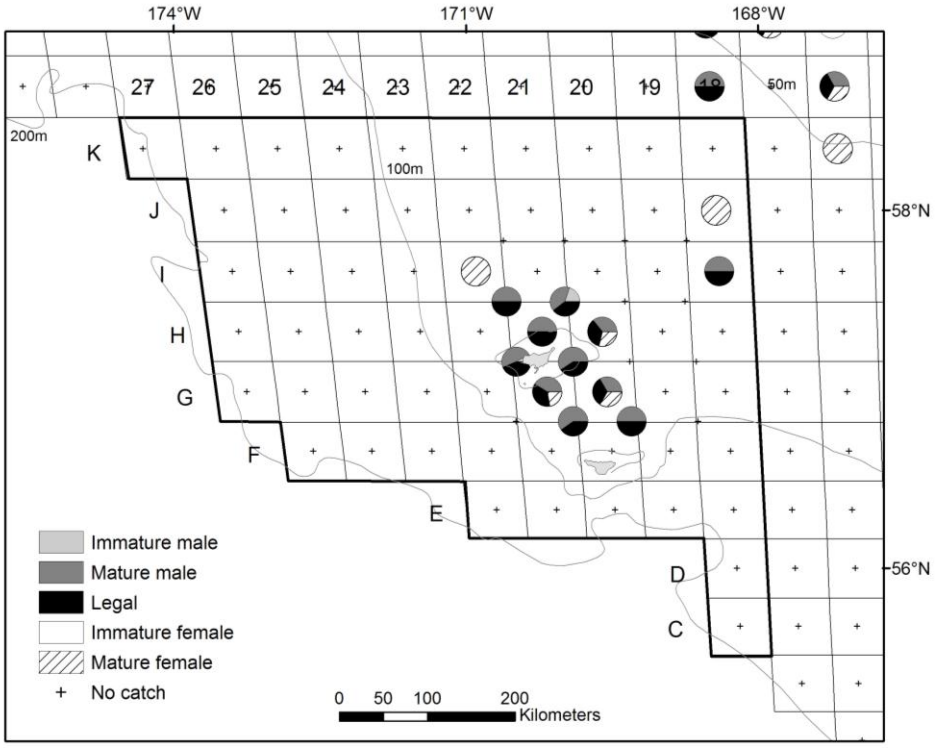

Figure 8. 2012 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

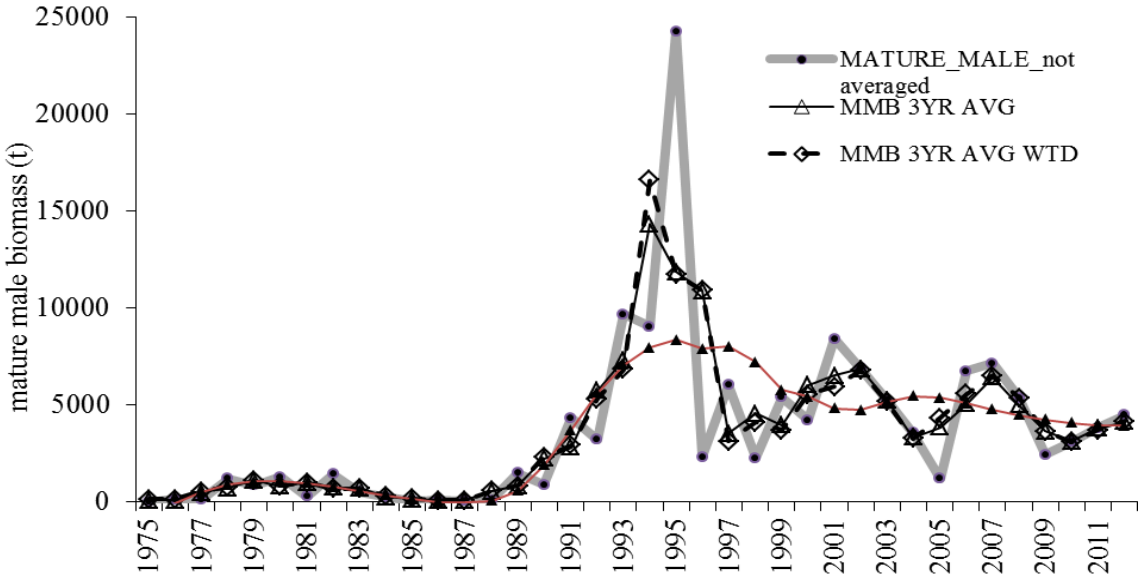

Figure 9. Alternative average biomass options including non-weighted average, average weighted by inverse CV, and loess for calculating MMB in the most recent year.

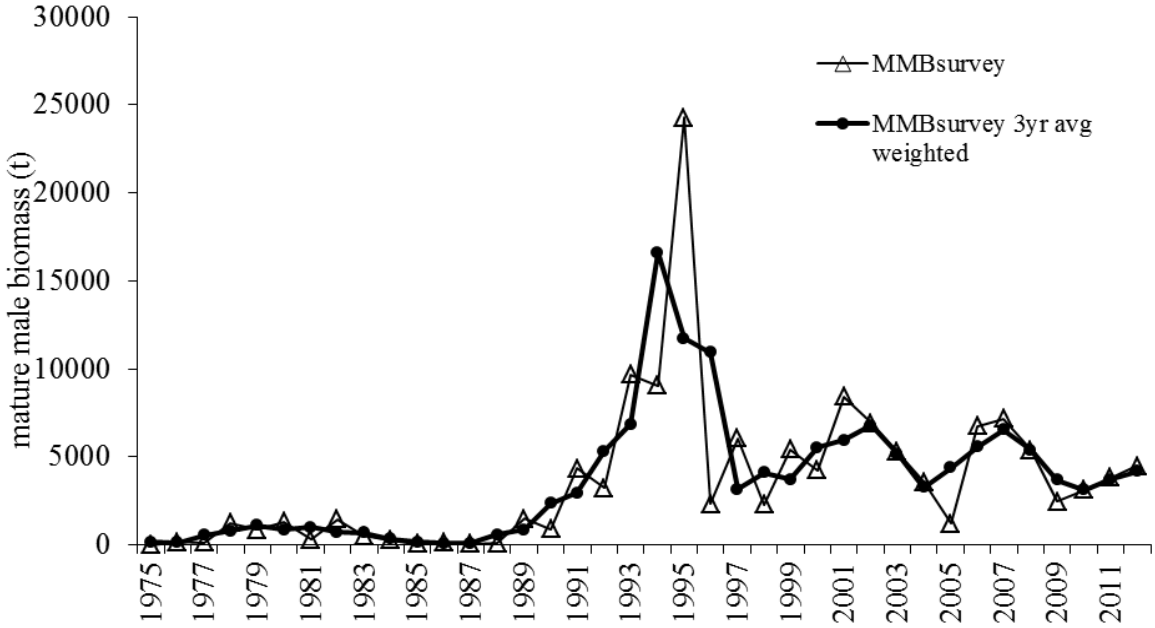

Figure 10. Time series comparison of MMB and the three year running average MMB at the time of the survey.

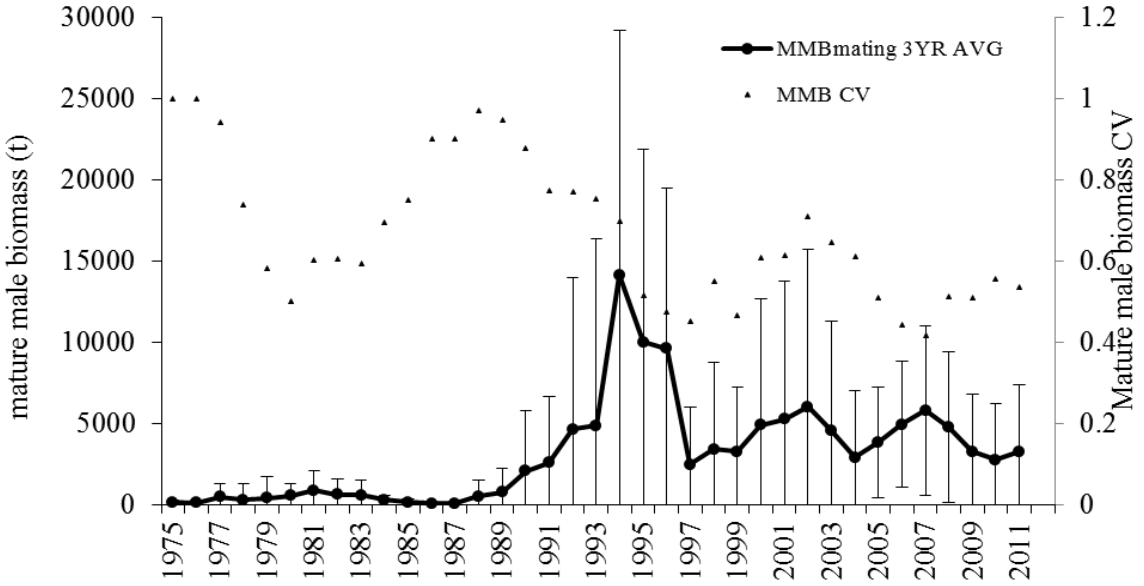

Figure 11. Time series of Pribilof Island red king crab 3 year weighted average mature male biomass (95% C.I.) and mature male biomass CV estimated from the NMFS annual EBS bottom trawl survey.

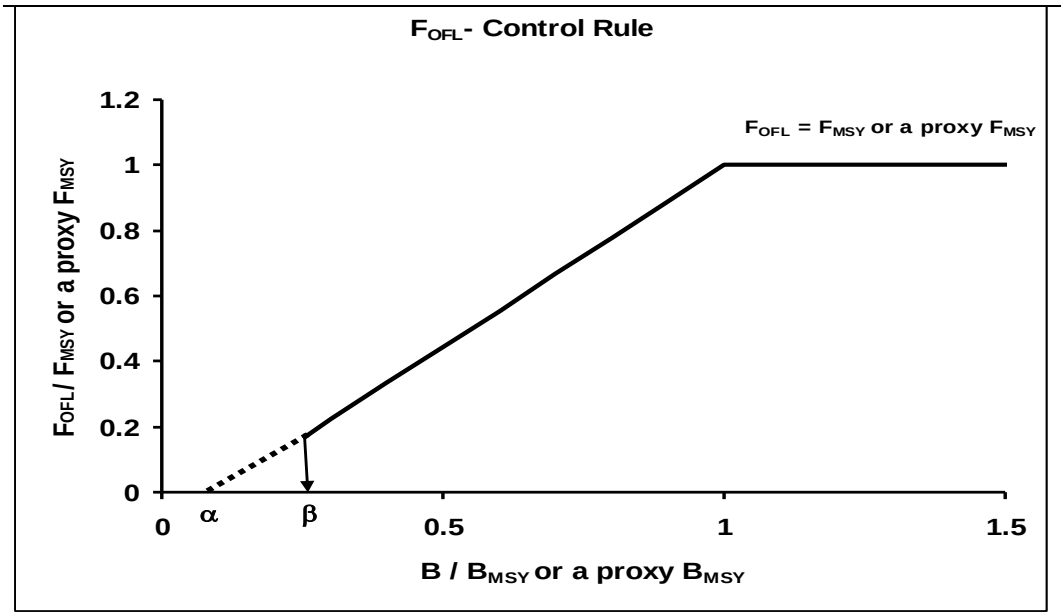

Figure 12. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

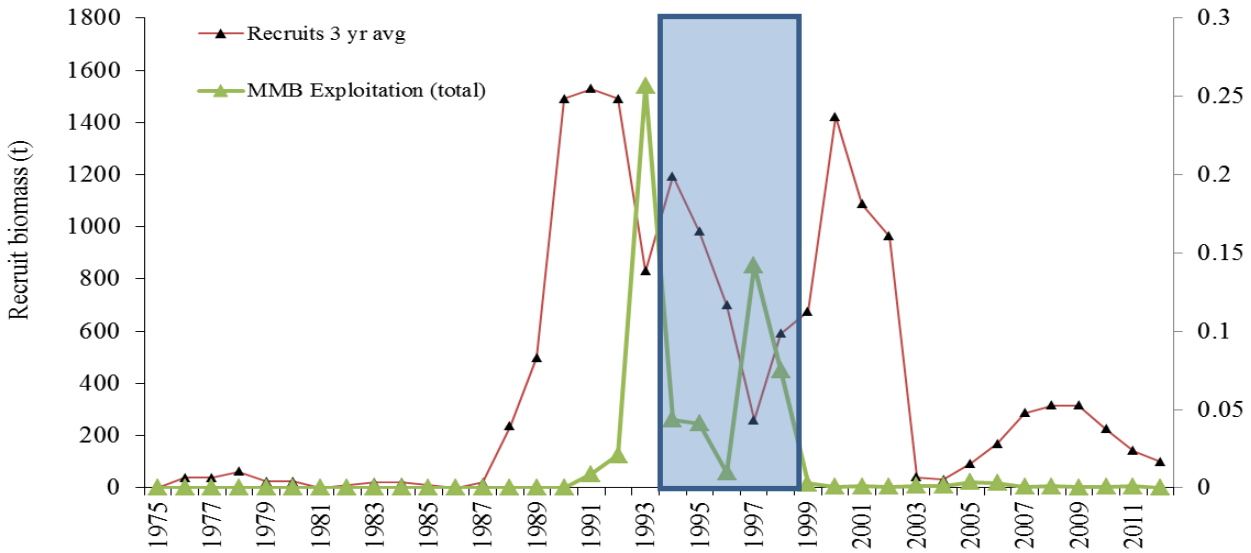

Figure 13. Time series of survey estimated recruit biomass (males 120-134 mm) and exploitation rate (based on total catch) of mature male biomass. The shaded region represents a period where commercial removals were occurring.

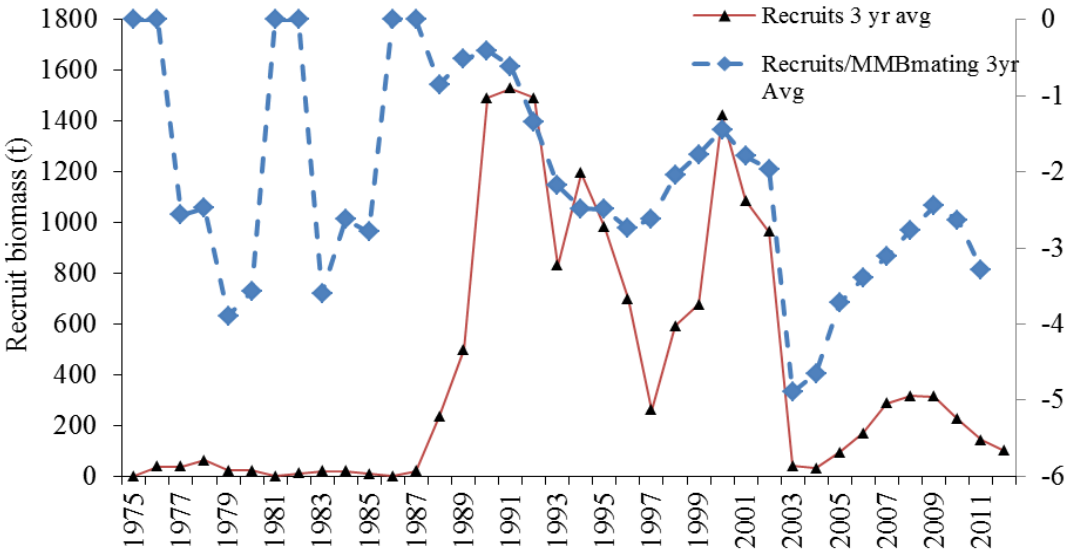

Figure 14. Time series of survey estimated recruit biomass (males 120-134 mm) and ln(Recruits/MMB). The shaded region represents a period where commercial removals were occurring.

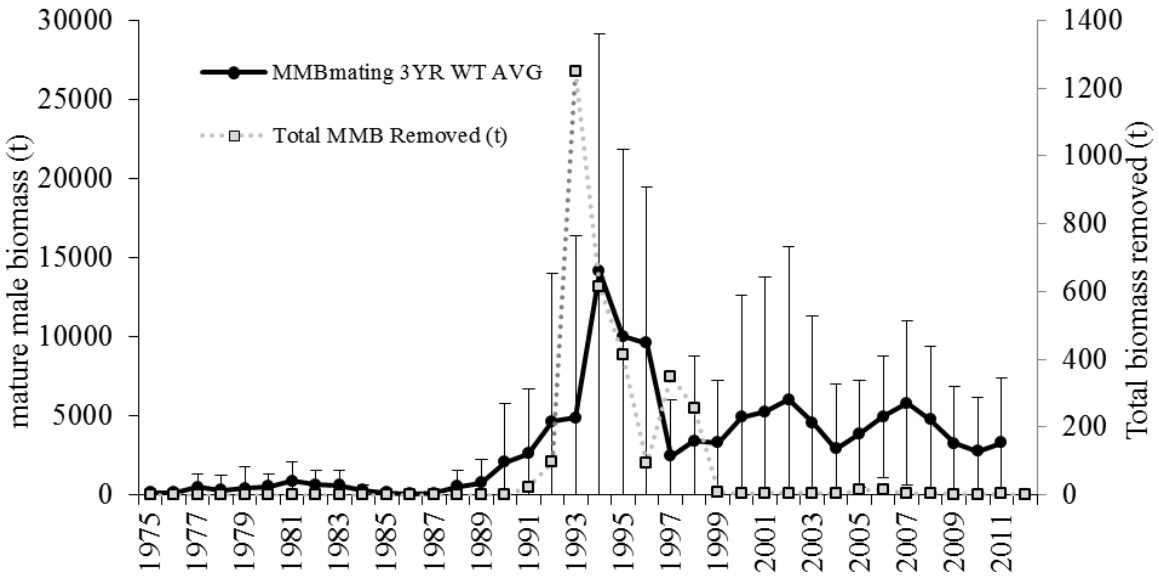

Figure 15. Time series of survey estimated Pribilof Island red king crab 3 year moving averaged mature male biomass at mating (95% C.I.) and total catch removals.